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International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G01B 11/03, 11/08, G06T 5/40	A1	(11) International Publication Number: WO 98/02716 (43) International Publication Date: 22 January 1998 (22.01.98)

(21) International Application Number: PCT/US97/10833

(22) International Filing Date: 19 June 1997 (19.06.97)

(30) Priority Data:
08/680,342 12 July 1996 (12.07.96) US

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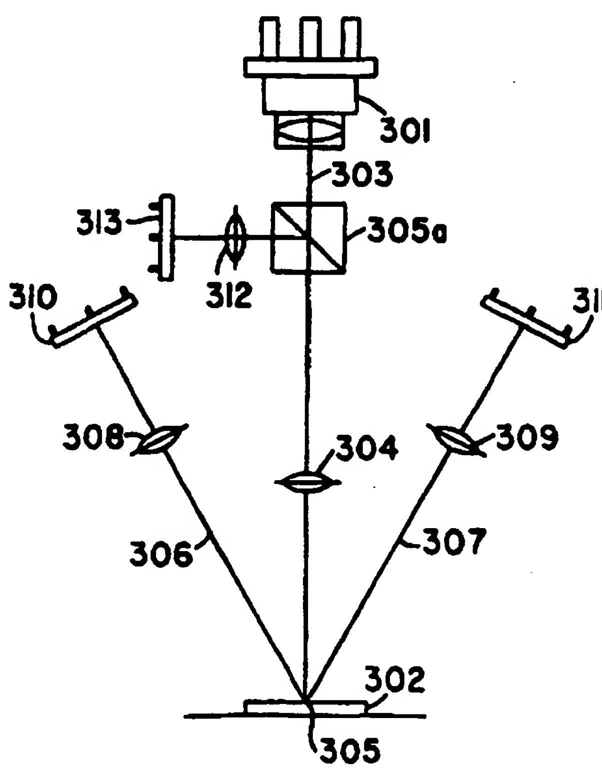
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: METHOD AND SYSTEM FOR MEASURING OBJECT FEATURES

(57) Abstract

A system is provided that simultaneously gathers three-dimensional and two-dimensional data for use in inspecting objects such as chip carriers for defects. Specifically, a source laser beam (303) is directed to an object and forms a spot (305) at the point of impingement at a known X-Y position on the object. The laser beam is reflected at the spot and light reflected off-axially (306, 307) with respect to the source laser beam (303) is detected by two position sensing detectors (PSDs) (310, 311). Simultaneous to detecting off-axially reflected light, retro-reflected light (i.e., the light reflected approximately co-axial with the source laser) is detected by a photo diode array (313). Three dimensional object information is determined from the position sensing detector (310, 311) signals and two-dimensional object information is determined from the photo diode array (313) signal.



One typical way of measuring the dimensions of contacts or leads on chip carriers is through the use of a three dimensional (3-D) vision system that employs optical triangulation techniques. U.S. Patent No. 5,465,252 issued to Bilodeau et al. (the "'152 patent"), expressly incorporated herein by reference, describes one such system. A light source such as a laser is positioned to illuminate an object (such as a packaged semiconductor chip) at a specific X-Y position. The source laser beam is directed through an optical system and forms a focused spot at the point of impingement on the object. The focused spot is reflected and light reflected off-axially with respect to the source laser beam is focussed on a light sensor. The image location (i.e., the point where the reflected spot impinges the light sensor) is related, using standard optics principals, to the location of the light spot on the object, which, in turn, can be used to determine image height (Z location). Calibrated processing electronics are used to calculate the height of the object and store the object height with its associated X-Y location. The light source is then positioned to different X-Y locations, and the process is repeated until 3-D data is gathered for the entire object (or a portion thereof). The stored data is then be compared to a manufacturer's specification for the object (or portion thereof) to determine whether the object is defective.

Known 3-D vision systems, such as the system described above, provide accurate results for measuring the dimensions of leads on chip carriers, and for coplanarity inspection of BGAs. However, there is difficulty in obtaining accurate dimensions (such as diameters) of ball, bump, and hemispherically shaped contacts, such as those found on certain chip carriers (e.g., BGAs). This difficulty is largely due to "shadow" effects. Known 3-D vision systems cannot accurately capture data concerning

exemplary embodiment, a system is provided that simultaneously collects three-dimensional and two-dimensional data for use in inspecting objects such as chip carriers for defects. Specifically, a source laser beam is directed to an object and forms a spot at the point of impingement at a known X-Y position on the object. The laser beam is reflected at the spot and the light reflected off-axially with respect to the source laser beam is detected by two position sensing detectors (PSDs).

Simultaneous to detecting off-axially reflected light, retro-reflected light (i.e., the light reflected approximately co-axial with the source laser) is detected by a photo diode array. In this manner, visibility is obtained to the entire upper hemisphere of features such solder balls and bumps.

Analog signals generated by the PSDs related to the position(s) where the reflected light impinged the PSDs, are used to calculate the Z coordinate of the object (i.e., the height) at the point of impingement of the source laser beam on the object. This value is calculated using standard optical triangulation principals. The three-dimensional (3-D) information can then be compared to manufacturer's specifications for the chip carrier to determine if, for example, each solder ball or bump on a chip carrier such as a ball grid array, is the correct height. Additionally, the information can be used for determining coplanarity.

The amplitude of the reflected light that is received by each PSD at the known X-Y positions may be used to form an image of the reflected energy on a point by point basis. However, the resulting images (one per PSD) will suffer from the same shadowing effects as the three dimensional data that is simultaneously gathered.

description of exemplary embodiments taken in conjunction with the attached drawings wherein:

Fig. 1 is a diagram of a prior art vision system;
Fig. 2 is an illustration of "shadow" effects;
Fig. 3 is a diagram of a first exemplary embodiment of the present invention;
Fig. 4 is a flowchart illustrating the categorization of each collected intensity value in the 2-D array;
Fig. 5 is the 2-D image of a solder ball as categorized by the process of Fig. 4;
Fig. 6 is a flowchart of the determination of a threshold intensity value;
Fig. 7 is a histogram of a 2-D image of a exemplary solder ball on a BGA;
Fig. 8 is a flowchart of the analysis of the 2-D categorized data;
Fig. 9 illustrates the projection of a 2-D image onto the X and Y axes;
Fig. 10 is a flowchart of the analysis of the 3-D data;
Fig. 11 is a block diagram of a second representative embodiment of the present invention; and
Fig. 12 is a block diagram showing further details of the optical system of Fig. 11.

Detailed Description

Prior Art Vision System: Referring now to the drawings, and initially Fig. 1, there is illustrated a typical prior art vision system. A source of light, i.e., laser 101, is positioned to illuminate an object such as a chip carrier 102. A laser beam 103 from laser 101 is directed through an optical system 104 and forms a focused spot 105 at the point of impingement on the chip carrier 102 at a known X-Y position. The laser beam 103 focussed at spot 105 is reflected. The light reflected off-axially

measured, but it can be determined using complex fitting techniques. However, the accuracy of the results obtained may be less than the required accuracy.

Exemplary Embodiment: Fig. 3 is a diagram of an exemplary embodiment of the present invention which overcomes many of the problems found in the prior art. A source of light, laser 301 (e.g., a gas laser, or a laser diode and collimator), is positioned to illuminate an object such as a chip carrier 302. A laser beam 303 from laser 301 is directed through a beam splitter 305a and is focussed through an optical system 304 to form a focused spot 305 at the point of impingement on the chip carrier 302 at a known X-Y position. (It will be understood by those of ordinary skill that the light may, instead, be focussed or deflected as a slit, plane of light, or other shape.) The laser beam 303 is reflected by the chip carrier 302 at spot 305. The light reflected off-axially with respect to source laser beam 303 (306, 307) is focussed through two optical systems 308 and 309 on two photo sensitive devices such as, for example, PSDs 310 and 311. (It should be noted that other photo sensitive devices can also be used such as, for example, charge coupled devices (CCDs), or photo diode arrays.) The height (Z-location) at the X-Y position of the object (at the point of impingement of the source laser beam) is then calculated as was described in connection with Fig. 1. Accordingly, 3-D data (i.e., X, Y, and Z coordinates) is obtained, providing a 3-D image of the object at that X-Y location of the object. It will be understood by those of ordinary skill that the 3-D data can be obtained by detecting light reflected (off-axially with respect to the source laser beam) along a single path (and, accordingly, using a single photo sensitive device) rather than along two paths as described above.

are first initialized to refer to the first X-Y intensity value (step 401). Intensity value Y(i,j) is compared to a threshold intensity value T (step 402) (the determination of the threshold value is described below in connection with Fig. 6). If Y(i,j) has an intensity value that is greater than the threshold value T, then Y(i,j) is designated "background" (i.e., it is either the center of the ball/bump or the area surrounding the ball/bump), thus l(i,j) (wherein l(i,j) denotes the label of Y(i,j)) is set to 0 (step 403). If, however, Y(i,j) has an intensity value that is less threshold value T, then Y(i,j) is an edge point of the ball/bump and l(i,j) is set to 1 (step 404). This process is repeated until all of the intensity values in the 2-D array have been compared to the threshold value T (see steps 405, 406). For solder balls and bumps, a typical result is a ring shaped image as shown in Fig. 5.

Determination of a Threshold Intensity Value: In the representative embodiment of the present invention, the threshold value is determined using a fast, iterative procedure as shown in the flowchart of Fig. 6. First, a portion of a sample chip carrier, for example, a portion including a solder ball, is imaged using the system described in connection with Fig. 3 (step 601). In the representative embodiment, only the 2-D data collected from the photo diode array 313 is utilized in the threshold value determination. Thus the 3-D data collected from PSDs 310 and 311 need not be stored.

Next, the cluster center M (i.e., the mass center) of the data is determined (step 602). In particular:

$$M = 1/N * \sum_{i,j} Y(i,j),$$

where N is the total number of data samples (i.e., an averaging function). M is then split into two new cluster centers, i.e., M0 = M + p and M1 = M - p

(step 802). Additionally, the X center position is calculated (step 803), i.e., X center = X1 + (X2 - X1)/2.

Next, the 2-D image is projected onto the Y-axis (step 804). Y positional information and the Y diameter of each ball is determined based on this projection, i.e., Y diameter = Y2 - Y1 (where Y1 and Y2 are the minimum and maximum Y coordinates of the projected image)(step 805). The Y center position is then calculated (step 806), i.e., Y center = Y1 + (Y2 -Y1)/2.

The combination of the two center coordinates, i.e., X center and Y center, defines the ball center coordinates (step 807), i.e., ball center = (X center, Y center).

It will be understood by those of ordinary skill that the order of the steps illustrated in the flowchart of Fig. 8 is merely exemplary. Many of the steps could be done in a different order.

Fig. 9 illustrates the projection of the 2-D image onto the X and Y axes. Specifically, image 901 is shown projected onto the X axis 902, and the Y axis 903.

Analysis of the 3-D Data: In the representative embodiment of the present invention, the 3-D data is analyzed to determine i) the height of each solder ball; and ii) chip carrier coplanarity. In accordance with the flowchart of Fig. 10, the data collected from PSDs 310 and 311 is used to determine the height of each solder ball in accordance with well-known optical triangulation techniques (step 1001). As is understood by those of ordinary skill, the point where a reflected spot impinges the PSDs 310 and 311 is related to the location of the light spot on the object, which, in turn, can be used to determine image height (Z location). The respective image heights can then be compared to each other in order

Data collected by the optical system 1101 is transmitted as an analog signal to the process electronics 1105. The process electronics 1105, which includes, for example, digital signal processors (DSPs), digital to analog (D/A) converters, analog to digital (A/D) converters, and input/output (I/O) and communication links, receives and processes the analog data. The processed data is then transmitted to the computer 1104 for analysis. The results of the analysis are reported to an operator on output device 1106.

Fig. 12 shows the optical portion of the system of Fig. 11 in more detail. A light source 1201 (for example, an 830nm diode laser) controlled by process electronics 1105, is positioned by gantry 1102 to illuminate an object such as a chip carrier 1202. Light, e.g., a laser beam 1203, is directed to a deflector 1204 which selectively deflects the laser beam 1203.

The deflector 1204, controlled by process electronics 1105, includes, for example, an acousto-optic (A.O.) deflector. The laser beam 1203 can be quickly "swept" across a predetermined area of the chip carrier 1202 by continuously changing the drive frequency to the A.O. deflector and thereby continuously changing the deflection of the laser beam 1203. Accordingly, the motion mechanism of the gantry 1102, in combination with the deflector 1204, precisely determine the X-Y position (and quickly change the X-Y postion) on the object 1202 that the laser beam 1203 will impinge upon.

From the deflector 1204, the laser beam 1203 is directed to a polarizing beam splitter cube 1205 through an optical system 1206 (comprised of, for example, two plano-convex cylindrical lenses, f=60mm, and f=22.2mm, a lens, f=40mm, and a half wave plate). The beam splitter

to the surface of the page. Accordingly, beam splitter 1205 reflects the retro-reflected light through an optical system 1216 (comprised of, for example, an achromatic lens, f=50mm) onto a photo diode array 1217. The analog signals generated by the photo diode array 1217 related to the intensity of light impinging the photo diode array 1217 and the optional normalization photo diode 1219 intensity are transmitted to the process electronics 1105.

The analog signals from the photo sensitive devices, i.e., PSDs 1214 and 1215, and photo diode arrays 1217 and 1219 are processed and analyzed by process electronics 1105 and computer 1104. In particular, the analog signals are converted to digital signals (via an A/D convertor). Z coordinates are determined from the data received from the PSDs 1214 and 1215 as described above. The data collected from photo diode array 1219 (i.e., representing the intensity of the source laser beam) is used to normalize the data collected by photo diode array 1217 (in order to maintain the accuracy of the data in the event of fluctuating laser output). The process electronics 1105 then assembles data from the photo diode arrays 1217 and 1219, the Z coordinates, and the X and Y positions into data packets and transmits the packets to the computer 1104. The computer 1104 receives the packets and performs the algorithms described in connection with Figs. 4-10. The computer 1104 also provides an interface to a user.

As is clear from the foregoing, the present invention provides a means to determine quickly and accurately feature dimensions without the use of complex curve fitting algorithms. Furthermore, 3-D data and 2-D data are simultaneously collected. Accordingly, the object need only be scanned once to obtain all the information necessary to determine the feature dimensions.

WHAT IS CLAIMED IS:

1. A method for determining at least two dimensions of an object comprising the steps of:

a) illuminating at least a portion of the object with light transmitted by a light source along a first path;

b) detecting light reflected along a second path spaced from the first path from the object at a first preselected position;

c) forming a first image of the illuminated portion of the object as a function of the light detected in step b);

d) simultaneously with step b), detecting light retro-reflected within the first path from the object at a second preselected position;

e) forming a second image of the illuminated portion of the object as a function of the light detected in step d;

f) determining at least one first dimension of the object as a function of the first image; and

g) determining at least one second dimension of the object as a function of the second image.

2. The method of claim 1 wherein step a) further comprises:

illuminating the at least a portion of the object at a predetermined X-Y coordinate.

3. The method of claim 2 wherein the at least one first dimension is a Z coordinate of the object.

4. The method of claim 2 wherein the at least one first dimension is a plurality of Z coordinates of the object.

5. The method of claim 1 wherein step g) further comprises the steps of:

7. The method of claim 6 wherein the function of step q is an averaging function.

8. The method of claim 1 wherein the at least one second dimension is an edge coordinate of a feature on the object.

9. The method of claim 1 wherein the at least one second dimension is a diameter of a feature on the object.

10. A method for determining at least two dimensions of an object comprising the steps of:

a) illuminating at least a portion of the object at a predetermined X-Y coordinate with light transmitted by a light source along a first path;

b) detecting light reflected along a second path spaced from the first path from the object at a first preselected position;

c) forming a first image of the illuminated potion of the object as a function of the light detected in step b);

d) simultaneously with step b), detecting light retro-reflected within the first path from the object at a second preselected position;

e) forming a second image of the illuminated portion of the object as a function of the light detected in step d;

f) repeating steps a) - e) for a plurality different portions of the object at respective X-Y coordinates thereby forming a plurality of first respective images and a plurality of second respective images;

g) determining at least one first dimension of the object as a function of each of the plurality of first respective images; and

14. A method for determining at least one dimension of an object comprising the steps of:

a) obtaining a plurality of intensity values, the plurality of intensity values related to a sample object;

b) determining a first cluster center as a function of the plurality of intensity values;

c) determining first and second associated cluster centers, each a function of the first cluster center;

d) associating a first subset of the plurality of intensity values with the first associated cluster center;

e) associating a second subset of the plurality of intensity values with the second associated cluster center, wherein the second subset is different than the first subset;

f) updating the first associated cluster center as a function of the first subset;

g) updating the second associated cluster center as a function of the second subset;

h) repeating steps e-g until the first associated cluster center and the second associated cluster center converge; and

i) determining a threshold value as a function of converged first associated cluster center and second associated cluster center;

j) illuminating at least a portion of the object with light transmitted by a light source along a first path;

k) detecting light retro-reflected within the first path from the object at a preselected position;

l) forming a second image of the illuminated portion of the object as a function of the light detected in step d; and

m) determining at least one dimension of the object as a function of the first image and the threshold value.

20. The system of claim 15 wherein the second photo sensitive device is a photo diode array.

21. The system of claim 15 further comprising:

a third photo sensitive device at a third preselected position for detecting light reflected along a third path spaced from the first and second paths from the object and for generating a third signal representing information concerning the light detected along the third path; and

wherein the processing means is in communication with the third photo sensitive device and receives the third signal and generates a third image of the at least a portion of the object as a function of the third signal.

22. The system of claim 21 further comprising:

a fourth photo sensitive device at a fourth preselected position for detecting light transmitted from the light source along the first path and for generating a fourth signal representing information concerning the transmitted light; and

wherein the processing means is in communication with the fourth photo sensitive device and receives the fourth signal and processes the second signal as a function of the fourth signal.

23. An optical measurement system comprising:

a light source positioned to transmit light along a first path for illuminating at least a portion of the object;

a first photo sensitive device at a first preselected position for detecting light reflected along a second path spaced from the first path from the object and for generating a first signal representing

information concerning the light detected along the first path;

processing means, in communication with the first and second photo sensitive devices, for receiving the first signal and for generating a first image of the at least a portion of the object as a function of the received first signal, and for receiving the second signal and for generating a second image of the at least a portion of the object as a function of the received second signal, the processing further for determining at least one dimension of the object based on the first image and at least one second dimension of the object based on the second image.

25. The system of claim 24 wherein the deflector includes an acousto-optic deflector.

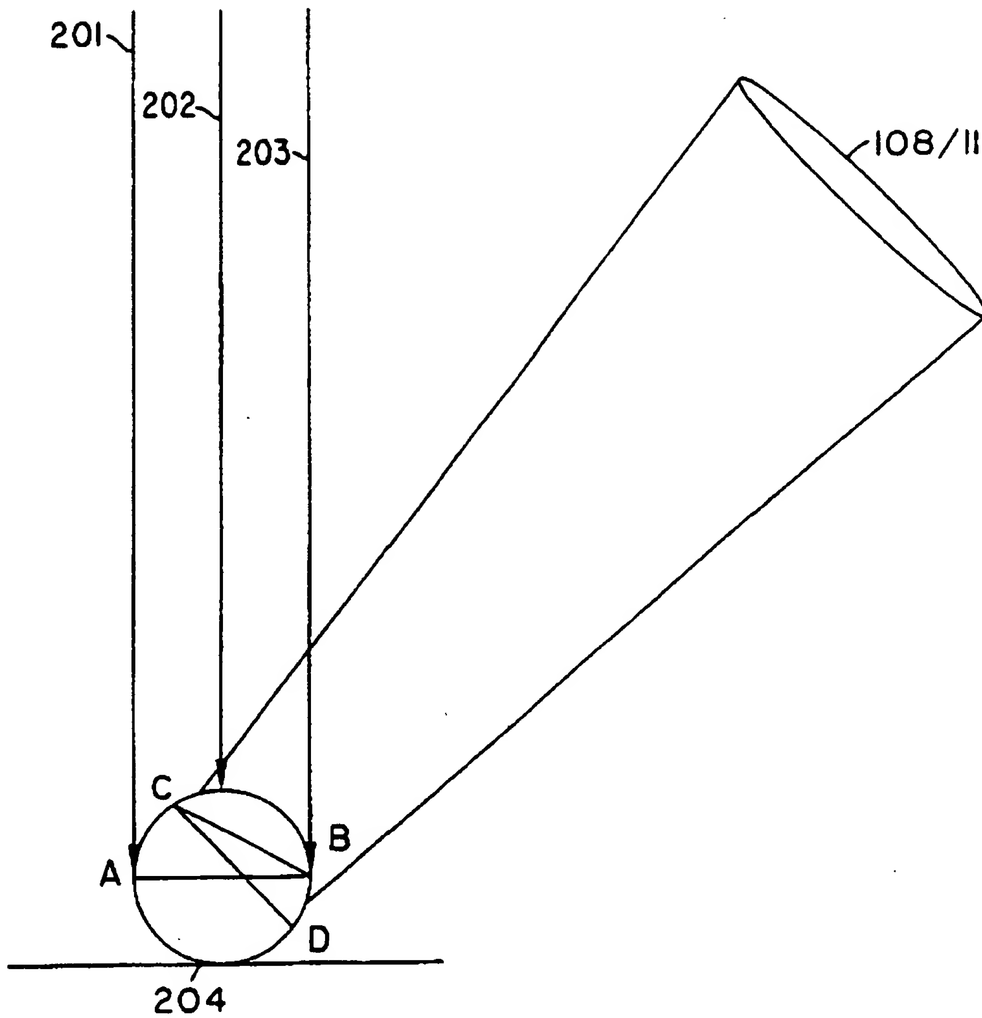


FIG. 2

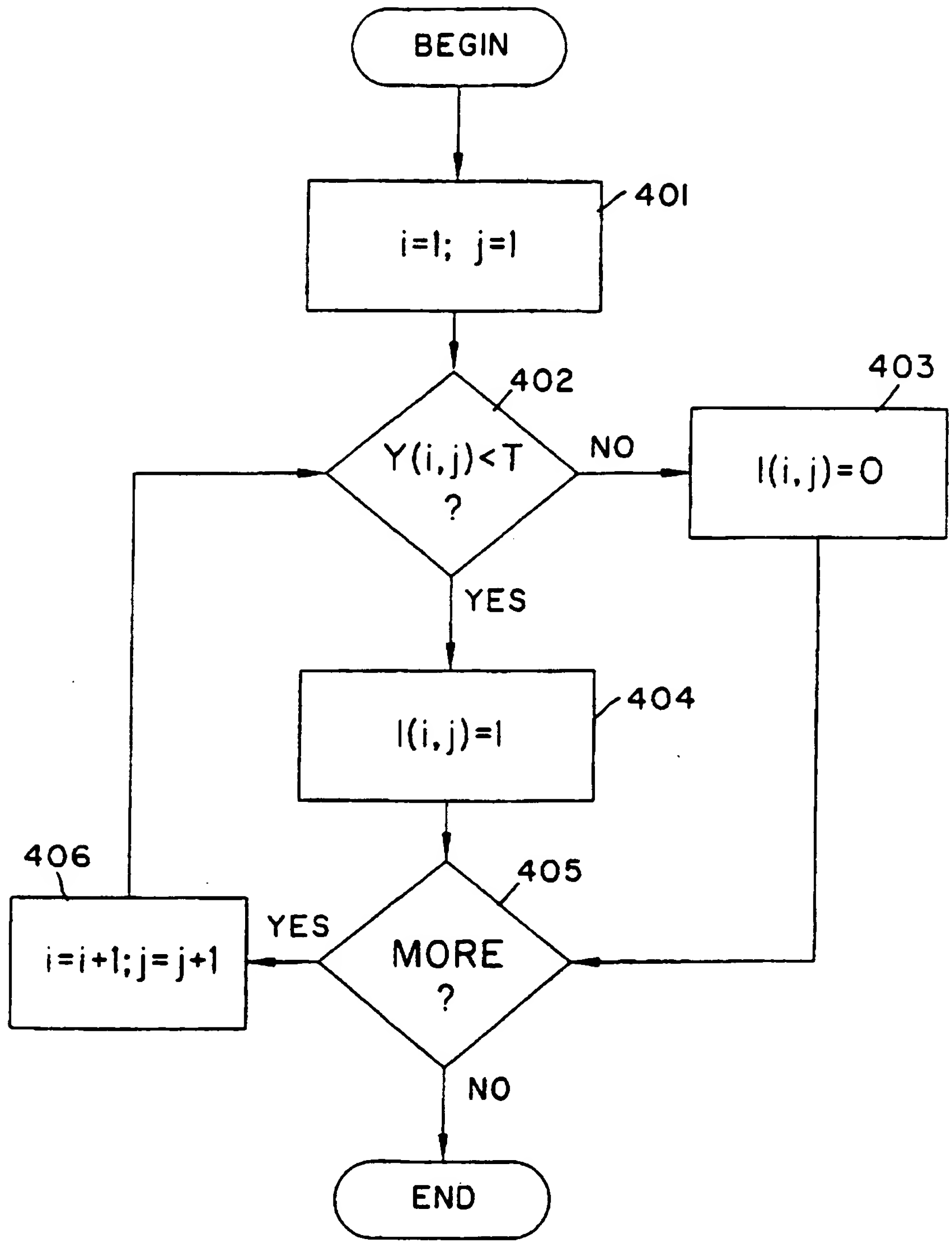

BEGIN
401
i=1; j=1
402
Y(i,j)<T ?
NO
403
I(i,j)=0
YES
404
I(i,j)=1
406
405
YES
i=i+1; j=j+1
MORE ?
NO
END

FIG. 4

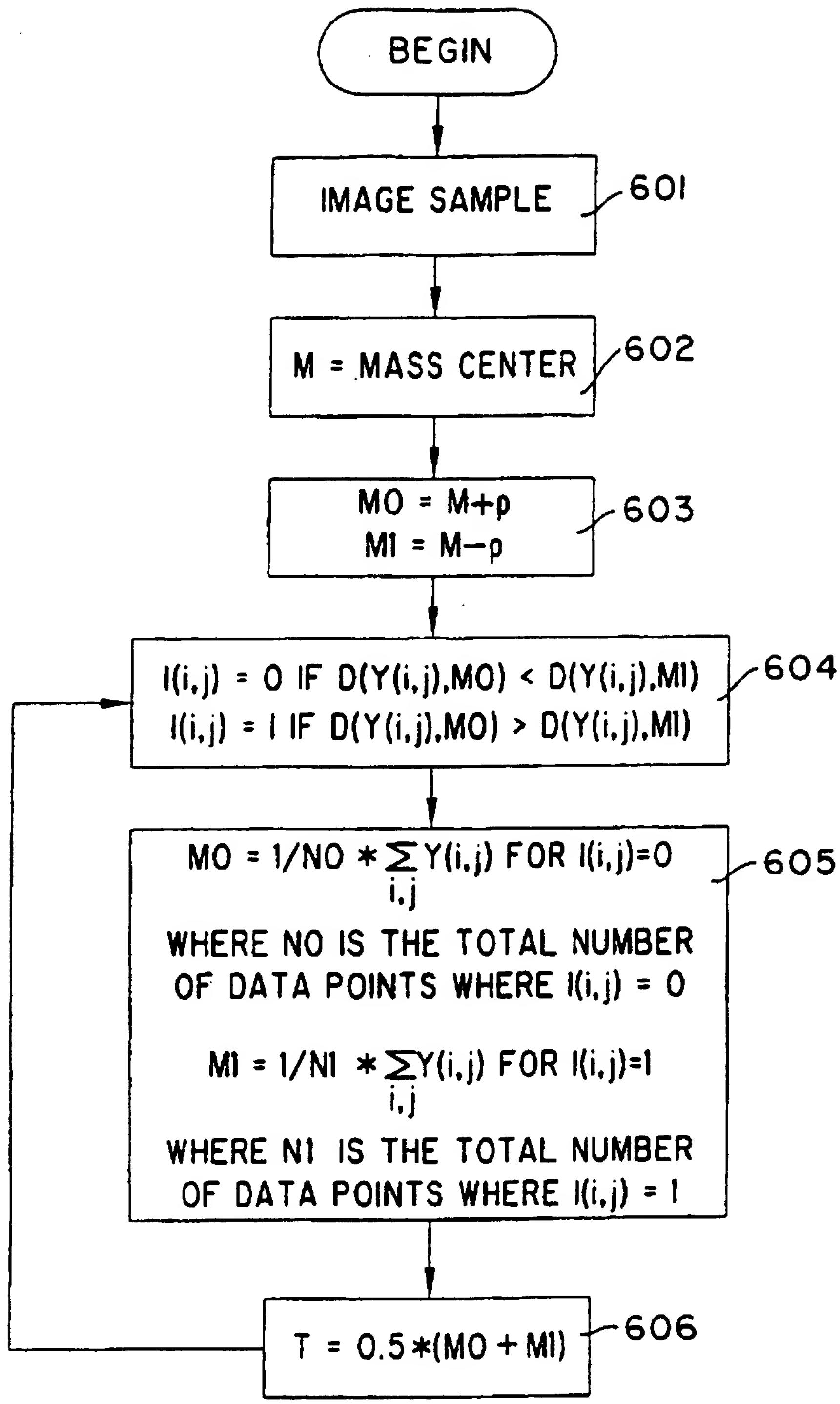

BEGIN
IMAGE SAMPLE
601
M = MASS CENTER
602
M0 = M+p
M1 = M−p
603
I(i,j) = 0 IF D(Y(i,j),M0) < D(Y(i,j),M1)
I(i,j) = 1 IF D(Y(i,j),M0) > D(Y(i,j),M1)
604
M0 = 1/N0 * Σ_{i,j} Y(i,j) FOR I(i,j)=0
WHERE N0 IS THE TOTAL NUMBER OF DATA POINTS WHERE I(i,j) = 0
M1 = 1/N1 * Σ_{i,j} Y(i,j) FOR I(i,j)=1
WHERE N1 IS THE TOTAL NUMBER OF DATA POINTS WHERE I(i,j) = 1
605
T = 0.5*(M0 + M1)
606

FIG. 6

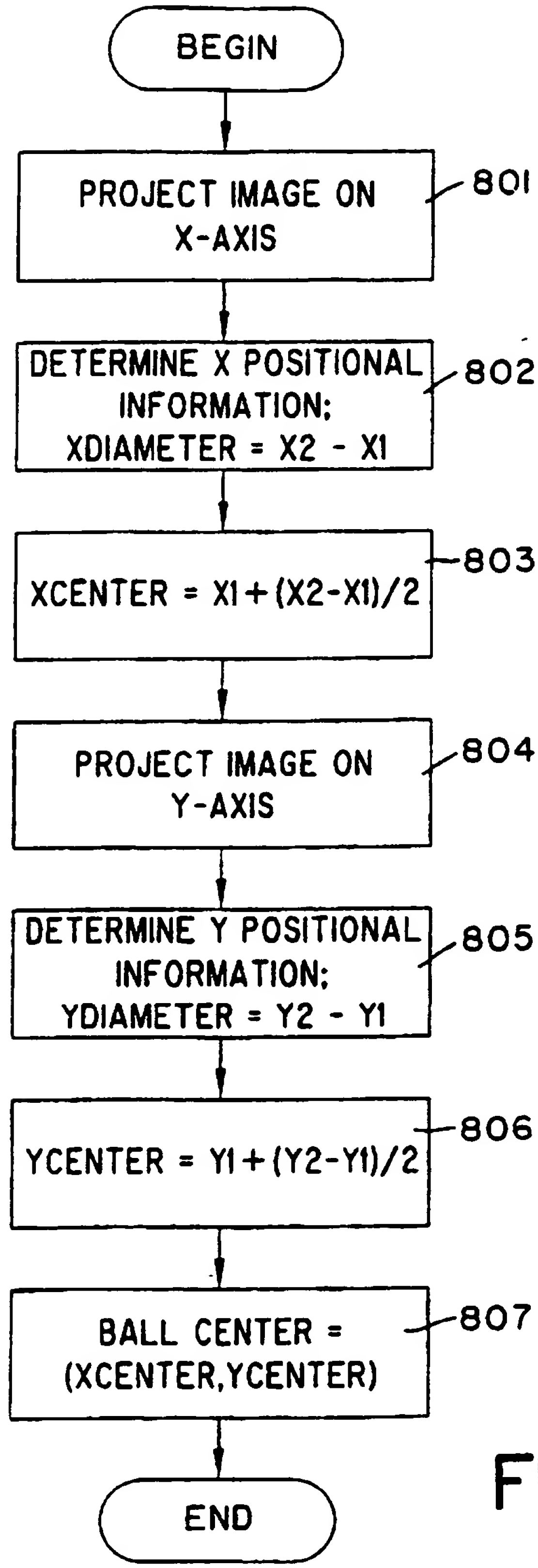

BEGIN
PROJECT IMAGE ON X-AXIS
801
DETERMINE X POSITIONAL INFORMATION; XDIAMETER = X2 - X1
802
XCENTER = X1 + (X2-X1)/2
803
PROJECT IMAGE ON Y-AXIS
804
DETERMINE Y POSITIONAL INFORMATION; YDIAMETER = Y2 - Y1
805
YCENTER = Y1 + (Y2-Y1)/2
806
BALL CENTER = (XCENTER,YCENTER)
807
END

FIG. 8

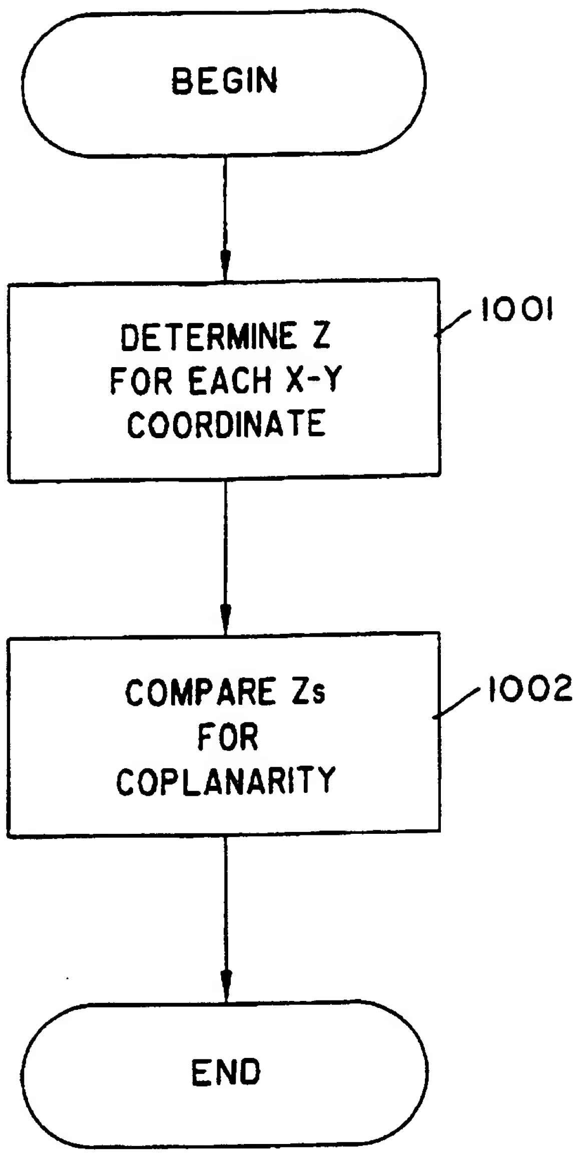
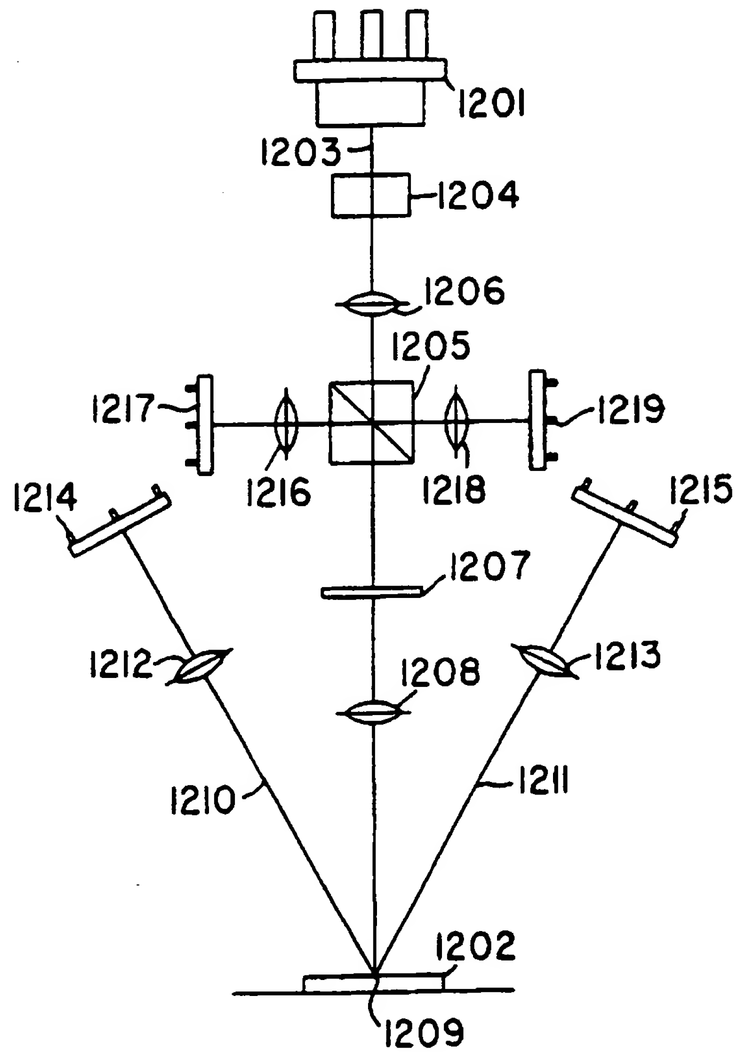

BEGIN
DETERMINE Z FOR EACH X-Y COORDINATE
1001
COMPARE Zs FOR COPLANARITY
1002
END

FIG. 10


1201
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1211
1202
1209

FIG. 12

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,075,872 A (KUMAGAI) 24 December 1991, col. 2, line 14 - col. 3, line 63.	6, 7, 14
Y	US 4,824,251 A (SLOTWINSKI ET AL.) 25 April 1989, col. 4, lines 29 - 34.	17